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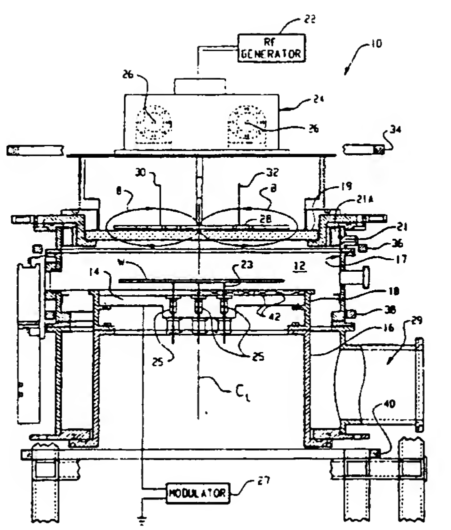
(54) Title: SYSTEM AND METHOD FOR PROVIDING IMPLANT DOSE UNIFORMITY ACROSS THE SURFACE OF A SUBSTRATE



(57) Abstract: A method and system is provided for enabling a uniform implant dose across the surface of a substrate, such as a semiconductor wafer (W), implanted within the process chamber (12) of a plasma immersion ion implanter (10). Plasma generated within the chamber includes desired dopant ions. Prior to processing wafers, ion current extracted from the plasma is determined by a dosimetry detector (42) at a plurality of locations in the chamber. The plurality of locations correspond to locations on the surface of a wafer to be implanted. A plurality of electromagnets (34, 36, 38, 40) generates a magnetic field within the chamber (12). The size, position, and current ratios for the electromagnets are selected to create a magnetic field within the chamber that is perpendicular to and uniform over the surface of the wafer. The dosimetry detector senses extracted ion current from the plasma at the plurality of locations within the chamber and outputs feedback signals representative thereof to a controller (50). The controller responds to the feedback signals and outputs a control signal to a power supply that controls the amount of electrical current in the plurality of electromagnets. The current is varied as necessary to achieve a uniform dose rate over the surface of the wafer. In a preferred embodiment, the plurality of electromagnets comprise a plurality of annular electromagnets that are disposed outside of and circumscribe the exterior of the process chamber.

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SYSTEM AND METHOD FOR PROVIDING IMPLANT DOSE UNIFORMITY ACROSS THE SURFACE OF A SUBSTRATE

Related Application

The following U.S. patent application is incorporated by reference herein as if it had been fully set forth: Application Serial Number: 09/369560, filed on 6 August, 1999, entitled System and Method for Improving Energy Purity and Implant Consistency, and for Minimizing Charge Accumulation of an Implanted Substrate.

Field of the Invention

The present invention relates generally to the field of plasma immersion ion implantation systems, and more specifically to an improved system and method for providing implant dose uniformity across the surface of a substrate implanted by such a system.

Background of the Invention

Ion implantation has become the technology preferred by industry to dope semiconductors with impurities in the large-scale manufacture of integrated circuits. Ion dose is one of two important variables in defining a particular implant process (the other being ion energy, which determines implant depth). Ion dose relates to the concentration of implanted ions for a given area or volume of semiconductor material. Typically, high current implanters (generally greater than 1 milliamp (mA) ion beam current) are used for high dose implants, while medium current implanters (generally capable of up to about 1 mA beam current) are used for lower dose applications.

A conventional ion implanter comprises three sections or subsystems: (i) an ion source for outputting an ion beam, (ii) a beamline including a mass analysis magnet for mass resolving the ion beam, and (iii) a target chamber which contains the semiconductor wafer or other substrate to be implanted by the ion

beam. Ion sources in ion implanters typically generate an ion beam by ionizing within a source chamber a source gas, a component of which is a desired dopant element, and extracting the ionized source gas in the form of an ion beam. The ion beam is directed along an evacuated beam path provided by the beamline. Energetic ions within the beam strike the substrate within the target chamber and are implanted therein. It is important in such an implantation system to insure implant dose uniformity across the surface of the substrate.

Plasma immersion ion implantation (PI-cubed or PI^3) is an emerging technology wherein a substrate such as a wafer on a platen is immersed within a plasma in a chamber. Thus, the chamber functions as both the processing chamber and the plasma source. Typically, a voltage differential is periodically established between the walls of the chamber and the platen to attract ions in the plasma toward the substrate. A sufficient voltage differential will result in ion implantation into the surface of the substrate. As in traditional ion implantation systems, it is important to insure implant dose uniformity across the surface of the substrate.

Accordingly, it is an object of the present invention to provide a system and method for providing implant dose uniformity across the surface of a substrate implanted by a plasma immersion ion implantation system.

Summary of the Invention

A system and method is provided for enabling a uniform implant dose across the surface of a substrate, such as a semiconductor wafer, implanted within the process chamber of a plasma immersion ion implanter. Plasma generated within the chamber includes desired dopant ions. Implantation is achieved by applying a stream of negative pulses to the platen holding the wafer. Prior to processing wafers, ion current extracted from plasma is determined by a dosimetry detector at a plurality of locations on the platen. The plurality of locations correspond to locations on the surface of a wafer to be implanted.

A plurality of electromagnets generates a magnetic field within the chamber. The size, position, and current ratios for the electromagnets are selected to create a magnetic field within the chamber that is perpendicular to and uniform

over the surface of the wafer. The dosimetry detector senses ion current extracted from the plasma at the plurality of locations within the process chamber, and outputs feedback signals representative thereof to a controller. The controller responds to the feedback signals and outputs a control signal to a power supply that controls the amount of electrical current in the plurality of electromagnets. The current is varied as necessary to achieve a uniform dose rate across of the wafer. In a preferred embodiment, the plurality of electromagnets comprise a plurality of annular electromagnets that are disposed outside of and circumscribe the exterior of the process chamber.

Brief Description of the Drawings

Figure 1 is a cross sectional plan view of a plasma immersion ion implantation system into which is incorporated one embodiment of a dose uniformity mechanism constructed according to the principles of the present invention;

Figure 2 is a block diagram showing a closed loop control system for controlling the current through the magnets in the system of Figure 1;

Figure 3 is a cross sectional view of the magnetic field created within the process chamber of the system of Figure 1, using the magnets shown therein; and

Figure 4 is a graphical representation of normalized plasma densities across the surface of a wafer in the chamber of Figure 3, for different values of magnetic current flowing through the magnets in the system of Figure 1.

Detailed Description of a Preferred Embodiment

Referring now to the drawings, Figure 1 discloses a plasma immersion ion implantation system, generally designated 10. The system 10 includes an evacuated process chamber 12 that is defined by an electrically activatable wafer support platen 14 mounted on insulator 18, an electrically grounded chamber housing 16 having walls 17, and a quartz window 19. Plasma generated within the chamber contains ions of a desired dopant species (*e.g.*, arsenic) that are implanted into a substrate, such as a semiconductor wafer W located therein, when a

negatively charged voltage is applied to the platen 14. As shown in Figure 1, the wafer W is lifted off of the platen by pins 23 operated by pin assemblies 25. In this manner the wafer may be readily installed into and removed from the plasma chamber via a loadlock assembly (not shown).

The plasma is generated in the process chamber 12 as follows. An ionizable dopant gas is introduced into the process chamber 12 by means of inlet 21 and perforated annular channel 21A that resides about the upper periphery of the chamber. A radio frequency (RF) generator 22 generates an RF signal (on the order of 13.5 megahertz (MHz)) which is coupled to a matching network 24. The matching network includes capacitors 26 that capacitively couple the RF signal to a generally planar antenna 28, having inner and outer circular coils, via leads 30 and 32. Matching the impedance of the RF generator 22 with that of the load insures maximum power out of the antenna 28 by minimizing reflection of the RF signal back into the generator. One such type of matching network 24 is known as an "inverted L" network wherein the capacitance of capactitors 26 is varied by servomotors, depending upon operating conditions.

The RF current generated within the antenna 28 creates a magnetic field that passes through the quartz window 19 into the process chamber 12. The magnetic field lines are oriented in the direction shown by arrows B, based on the direction of current through the antenna coils. The magnetic field penetrating the process chamber 12 through the quartz window 19 induces an electric field in the process chamber. This electric field accelerates electrons, which ionize the dopant gas, which is introduced into the chamber through annular channel 21A, to create a plasma. The plasma includes positively charged ions of the desired dopant that are capable of being implanted into wafer W when a suitable opposing voltage is applied to platen 14 by modulator 27. Because the implantation process occurs in a vacuum, the process chamber 12 is evacuated by pumps (not shown) via pump manifold 29.

The electric field induced in the process chamber is defined by annular field lines that are concentrated in a ring (toroid) that resides below and parallel to the plane of the antenna 28 (*i.e.*, at locations X and Y in the cross

sectional view of Figure 1). The plasma within the chamber 12 is therefore concentrated along these annular field lines. The plasma then diffuses to the wafer. Depending on the diffusion rate and chamber height, this can result in a plasma density at the wafer that ranges from being maximum at this annulus to being maximum at the center (including a uniform condition). However, the diffusion rate will depend on plasma conditions (species, pressure, RF power) which are chosen to optimize wafer processing, thus leaving only the chamber height as a control variable for uniformity. This is an inconvenient variable for uniformity control.

The present invention solves the problem of plasma density uniformity control by the addition of annular magnet coils 34, 36, 38, and 40 located outside of the process chamber 12. In the preferred embodiment, Helmholz coils (electromagnets) are used. The purpose of the coils is to vary the magnetic field within the process chamber 12 to effectively vary plasma diffusion rate, which varies the radial distribution of plasma density across the surface of the wafer.

In the preferred embodiment, the electromagnetic coils include two larger main coils 34 and 40 disposed above and below, respectively, two smaller trim coils 36 and 38, which reside closer in proximity to the process chamber 12. The larger main coils 34 and 40 are supplied by a first current source 44 and the smaller trim coils 36 and 38 are supplied by a second current source 46 (see Figure 2). Generally a first value of current is applied to both larger main coils and a second, lesser value of current is applied to the smaller trim coils. Alternatively, a single current source may be used to supply current to all four coils.

The wafer platen 14 includes a dosimetry detector such as a plurality of Faraday current collectors or cups 42 that are used to measure plasma current density and thereby provide an indication of implant dose. The Faraday cups may be constructed as shown in co-owned U.S. Patent Application No. 09/218,770. In the preferred embodiment, seven such cups are disposed coincident with a radius of the wafer platen.

The Faraday cups 42 are electrically biased and include a charged ion collecting surface parallel to the implantation surface. When a wafer is present on the platen during processing, the radially outermost Faraday cup may be used to

measure plasma current density and provide a real time feedback indication of the dose being implanted in the wafer. Prior to processing, when a wafer is not present on the platen, all of the Faraday cups may be used to provide an indication of the radial distribution of plasma current across the surface of the wafer, which corresponds directly to ion dose.

As will be further explained below, to adjust the radial distribution of plasma current density to insure a uniform implant dose, the magnetic field within the process chamber 12 is varied to effectively vary the distribution of plasma density within the chamber. The magnetic field is varied by altering the current through the magnetic coils.

Figure 2 shows a block diagram of a control system for controlling the current through the magnetic coils. The seven Faraday cups 42a - 42g provide signal outputs 43 to controller 50. Based on the Faraday cup readings, the controller outputs control signals 51a and 51b to the current sources 44 and 46 operating the larger main and smaller trim coils, respectively. In this manner, a closed loop control system is provided for controlling the distribution of plasma at the wafer.

Figure 3 is a cross sectional view of the magnetic field created within the process chamber of the system of Figure 1, using the magnets 34, 36, 38 and 40. The process chamber 12 is generally shown by the phantom outline of the chamber walls 17. Only one half of the chamber is shown in Figure 3 taken along chamber centerline C_L. It is assumed that the magnetic field created by the coils 34, 36, 38 and 40 is nearly identical for the other half of the chamber not shown.

Field lines B in Figure 3 define the magnetic field created within the chamber by the Helmholz coils. As can be seen from these magnetic field lines, the position of the coils in relation to the chamber 12, and the magnitude of the current flowing therein, causes a uniform magnetic field of up to 30 Gauss across the surface of the wafer W in the chamber 12. The uniform magnetic field is perpendicular to the wafer surface and uniform across the wafer surface. It is important that the field be uniform and perpendicular across the entire surface of the wafer to avoid any charging problems due to non-uniform electron trajectories during

the implant process. The wafer in this case has a diameter of 300 mm (30cm).

As shown in Figure 3, the coils provide a magnetic field that is uniform from the chamber centerline C_L radially outward in each direction for almost 20cm, thereby providing an area of uniform magnetic field within which the entire wafer W is positioned. The uniform magnetic field in the area immediately above the wafer W controls the plasma uniformity across the surface of the wafer. The plasma uniformity, in turn, insures a uniform implant across the surface of the wafer.

Figure 4 shows a graphical representation of normalized plasma densities across the surface of a wafer in the chamber of Figure 3, for different values of electric current flowing through the magnets. The graph of Figure 4 is for an argon plasma excited by an RF source operating at 200 watts. The magnetic field lobes of the antenna 28 (locations X and Y in Figure 3) are located 20 cm apart (*i.e.*, 10 cm to each side of centerline C_L). The current values from 6 amps to 16.9 amps shown in the legend represent current flowing through the larger main coils 24 and 40. The current flowing through the smaller trim coils 36 and 38 is .33 (33%) of the main coil current, which through experimentation has been found to be a suitable ratio.

The normalized plasma electron density shown in Figure 4 is measured 2 cm above the surface of the wafer by known means, such as by a traveling Langmuir probe. The Langmuir probe is repeatedly moved along the plane of the wafer to determine plasma density for a variety of magnet currents. Alternatively, the Faraday cups 42 may be used to measure the plasma density at the wafer surface.

Using either the traveling Langmuir probe or the Faraday cup array, plasma density across the surface of the wafer is determined. The controller 50 can then vary the magnetic field by adjusting the current in the magnets 34, 36, 38 and 40 until the desired uniform magnetic plasma density is obtained. If the Faraday cups are employed, the output signals of the Faraday cups may be used as feedback in a closed loop control system (refer back to Figure 2) to vary the magnet current in order to achieve lateral uniformity of plasma density.

As shown in Figure 4 two stable modes of plasma are obtained. In a

first mode, at lower main magnet current (6-8 amps), plasma density is concentrated along the chamber centerline C_L. In a second mode, at higher main magnet current (12-17 amps), plasma density is concentrated at the two locations (+10 cm and −10 cm from C_L) that coincide with the magnetic lobes of the antenna 28. At an intermediate current (9-11 amps), a more uniform plasma density is achieved across the surface of the wafer. However, this is an unstable region and the plasma density shows a propensity to move into one of the above two modes that are more stable.

The reason for the existence of the two distinct plasma modes may be explained by the different diffusion rates of the plasma away from the electric field source that is represented by the toroid below the antenna 28. With a low magnetic field created by the magnets 34, 36, 38 and 40, the plasma lateral diffusion rate is high and the center of the toroid begins filling with plasma and eventually peaks at the centerline C_L. With a high magnetic field created by the magnets 34, 36, 38 and 40, the plasma lateral diffusion rate is low and the toroidal shape of the plasma is maintained.

Thus, the present invention contemplates two methods of achieving uniform plasma density across the surface of the wafer W. Using either the Faraday cup array or the traveling Langmuir probe, the precise current through main coils 34 and 40 may be determined that will result in a uniform plasma density across the surface of the wafer W. The wafer may then be implanted using a single implant process step.

Alternatively, because the above method involves a region of plasma instability, a two-step implant may be performed. Using either the Faraday cup array or the traveling Langmuir probe, a first implant is performed using the first plasma density mode, and a second implant is performed using the second plasma density mode. This two-step method provides a more stable plasma in each mode, as opposed to the single step method, although two separate implant process steps will necessarily require more time.

Accordingly, a preferred embodiment of a method and system for providing implant dose uniformity across the surface of a substrate has been

described. Using the present invention, dose uniformity of less than 2% variation across the surface of a 300 mm wafer has been achieved. With the foregoing description in mind, however, it is understood that this description is made only by way of example, that the invention is not limited to the particular embodiments described herein, and that various rearrangements, modifications, and substitutions may be implemented with respect to the foregoing description without departing from the scope of the invention as defined by the following claims and their equivalents.

CLAIMS:

1. In a plasma immersion ion implanter (10) having a process chamber (12) for implanting substrates (W) contained therein with ions present in a plasma generated therein, an implant dose control mechanism comprising:

(i) a plurality of electromagnets (34, 36, 38, 40) for generating a magnetic field within the chamber (12);

(ii) at least one power supply (44, 46) for supplying electrical current to said plurality of electromagnets;

(iii) a feedback mechanism (42) for sensing either extracted ion current or plasma density in said plasma at a plurality of locations within the chamber and outputting feedback signals (43) representative thereof; and

(iv) a controller (50) for receiving said feedback signals and outputting at least one control signal (51) to said at least one power supply to control the amount of electrical current in said plurality of electromagnets necessary to achieve a uniform plasma density or uniform implanted dose at the plurality of locations within the chamber.

2. The system of claim 1, wherein said feedback mechanism (42) is located within the chamber (12) on the surface of a platen (14) upon which a substrate is positioned during processing, and wherein said controller (50) controls the amount of electrical current in said plurality of electromagnets to achieve a uniform plasma density or uniform implanted dose over the surface of the platen (14).

3. The system of claim 2, wherein said plurality of electromagnets (34, 36, 38 and 40) are disposed outside of said process chamber (12).

4. The system of claim 3, wherein said plurality of electromagnets (34, 36, 38 and 40) comprises a plurality of annular electromagnets that circumscribe the exterior of the process chamber.

5. The system of claim 4, wherein said plurality of electromagnets (34, 36, 38, 40) includes at least one larger main electromagnet (34, 40) and at least one smaller trim electromagnet (36, 38), said smaller trim electromagnet operating at substantially lower current than said larger main electromagnet.

6. The system of claim 2, wherein said feedback mechanism (42) is a plurality of Faraday current collectors.

7. The system of claim 2, wherein said feedback mechanism (42) is a traveling Langmuir probe.

8. A method of implanting a substrate (W) in a process chamber (12) in a plasma immersion ion implanter (10), comprising the steps of:

(i) generating a plasma in the chamber (12);

(ii) generating a magnetic field within the chamber using a plurality of electromagnets (34, 36, 38, 40);

(iii) sensing ion current in said plasma using a feedback mechanism (42) at a plurality of locations within the chamber;

(iv) outputting feedback signals (43) representative of the sensed ion current; and

(v) receiving with a controller (50) said feedback signals and outputting at least one control signal (51) to at least one power supply to control the amount of electrical current in said plurality of electromagnets necessary to achieve a uniform plasma density or uniform implanted dose at the plurality of locations within the chamber.

9. The method of claim 8, wherein said feedback mechanism (42) is located within the chamber (12) on the surface of a platen (14) upon which a substrate is positioned during processing, and wherein said controller (50) controls the amount of electrical current in said plurality of electromagnets to achieve a

uniform plasma density or uniform implanted dose over the surface of the platen (14).

10. The method of claim 9, wherein said plurality of electromagnets (34, 36, 38 and 40) are disposed outside of said process chamber (12).

11. The method of claim 10, wherein said plurality of electromagnets (34, 36, 38 and 40) comprises a plurality of annular electromagnets that circumscribe the exterior of the process chamber.

12. The method of claim 11, wherein said plurality of electromagnets (34, 36, 38, 40) includes at least one larger main electromagnet (34, 40) and at least one smaller trim electromagnet (36, 38), said smaller trim electromagnet operating at substantially lower current than said larger main electromagnet.

13. The method of claim 9, wherein said feedback mechanism (42) is a plurality of Faraday current collectors.

14. The method of claim 9, wherein said feedback mechanism (42) is a traveling Langmuir probe.

15. A method of implanting a substrate (W) in a process chamber (12) in a plasma immersion ion implanter (10), comprising the steps of:

(i) generating a plasma in the chamber (12);

(ii) generating a magnetic field within the chamber using a plurality of electromagnets (34, 36, 38, 40);

(iii) sensing ion current in said plasma using a feedback mechanism (42) in a plurality of locations within the chamber;

(iv) outputting first feedback signals (43) representative of the sensed ion current;

(v) receiving with a controller (50) said first feedback signals and outputting a first control signal (51) to a power supply to control the amount of electrical current in said plurality of electromagnets necessary to achieve a first plasma density or implanted dose distribution across the plurality of locations within the chamber;

(vi) positioning a substrate (W) into the chamber and performing a first implant thereon;

(vii) sensing ion current in said plasma using a feedback mechanism (42) in a plurality of locations within the chamber;

(viii) outputting second feedback signals (43) representative of the sensed ion current;

(ix) receiving with a controller (50) said second feedback signals and outputting a second control signal (51) to the power supply to control the amount of electrical current in said plurality of electromagnets necessary to achieve a second plasma density or implanted dose distribution across the plurality of locations within the chamber; and

(x) performing a second implant on the substrate.

16. The method of claim 15, wherein said feedback mechanism (42) is located within the chamber (12) on the surface of a platen (14) upon which a substrate is positioned during processing, and wherein the substrate (W) is removed from the chamber after said first implant and repositioned in the chamber before said second implant to enable steps (viii) and (ix).

17. The method of claim 16, wherein said plurality of electromagnets (34, 36, 38 and 40) are disposed outside of said process chamber (12).

18. The method of claim 17, wherein said plurality of electromagnets (34, 36, 38 and 40) comprises a plurality of annular electromagnets that circumscribe the exterior of the process chamber.

19. The method of claim 18, wherein said plurality of electromagnets (34, 36, 38, 40) includes at least one larger main electromagnet (34, 40) and at least one smaller trim electromagnet (36, 38), said smaller trim electromagnet operating at substantially lower current than said larger main electromagnet.

20. The method of claim 16, wherein said feedback mechanism (42) is a plurality of Faraday current collectors.

21. The method of claim 16, wherein said feedback mechanism (42) is a traveling Langmuir probe.

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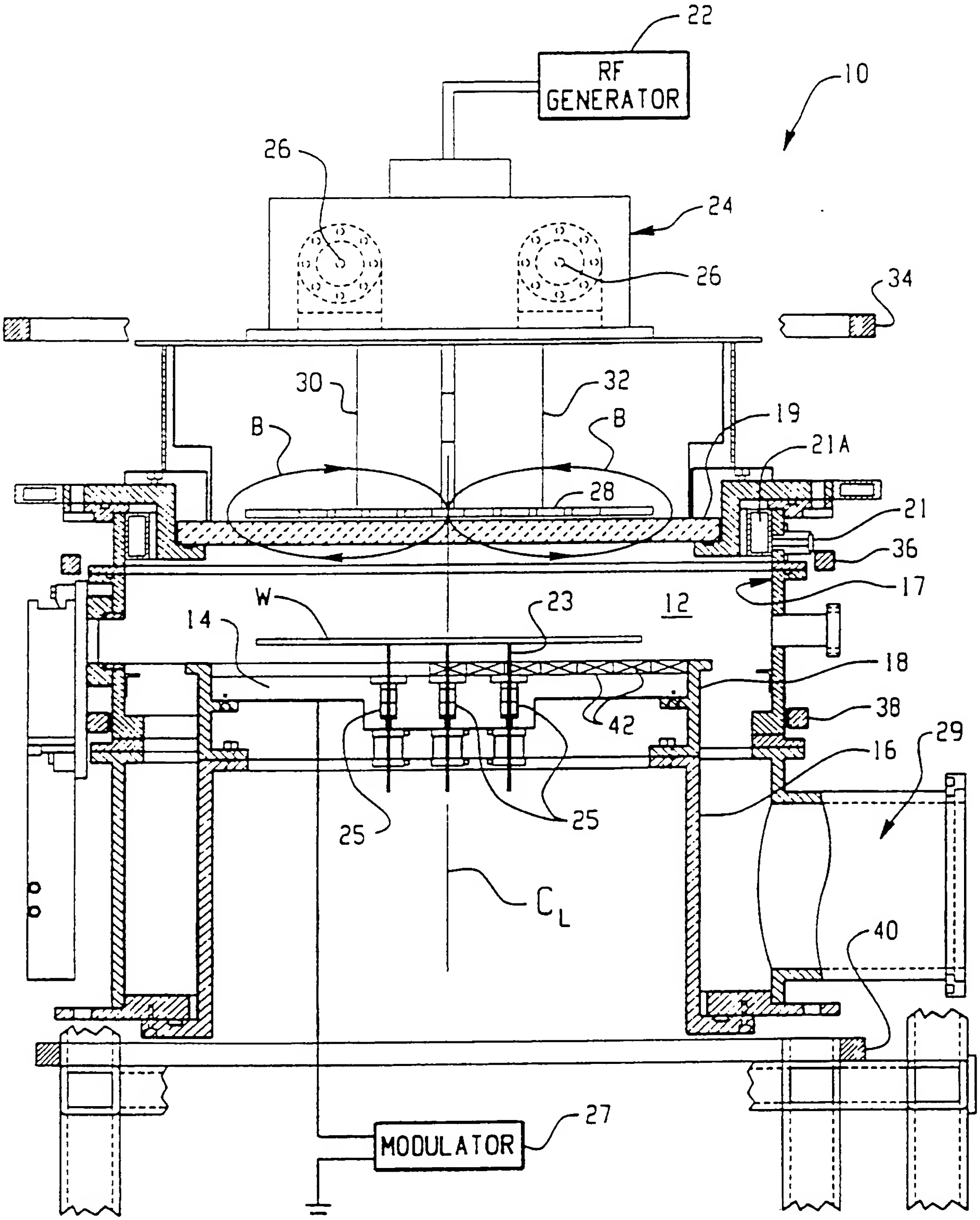
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MODULATOR
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Fig. 1

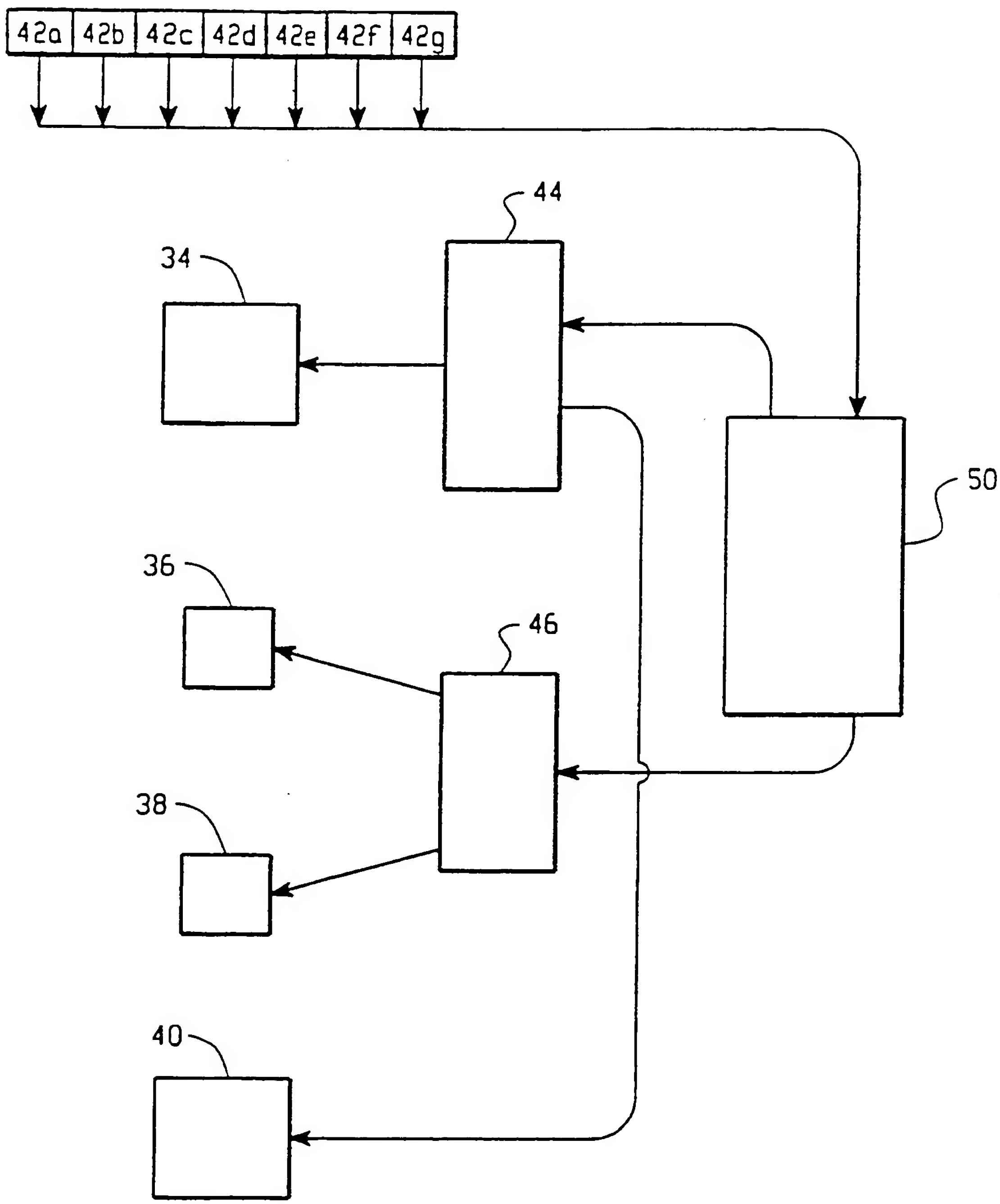

Fig. 2

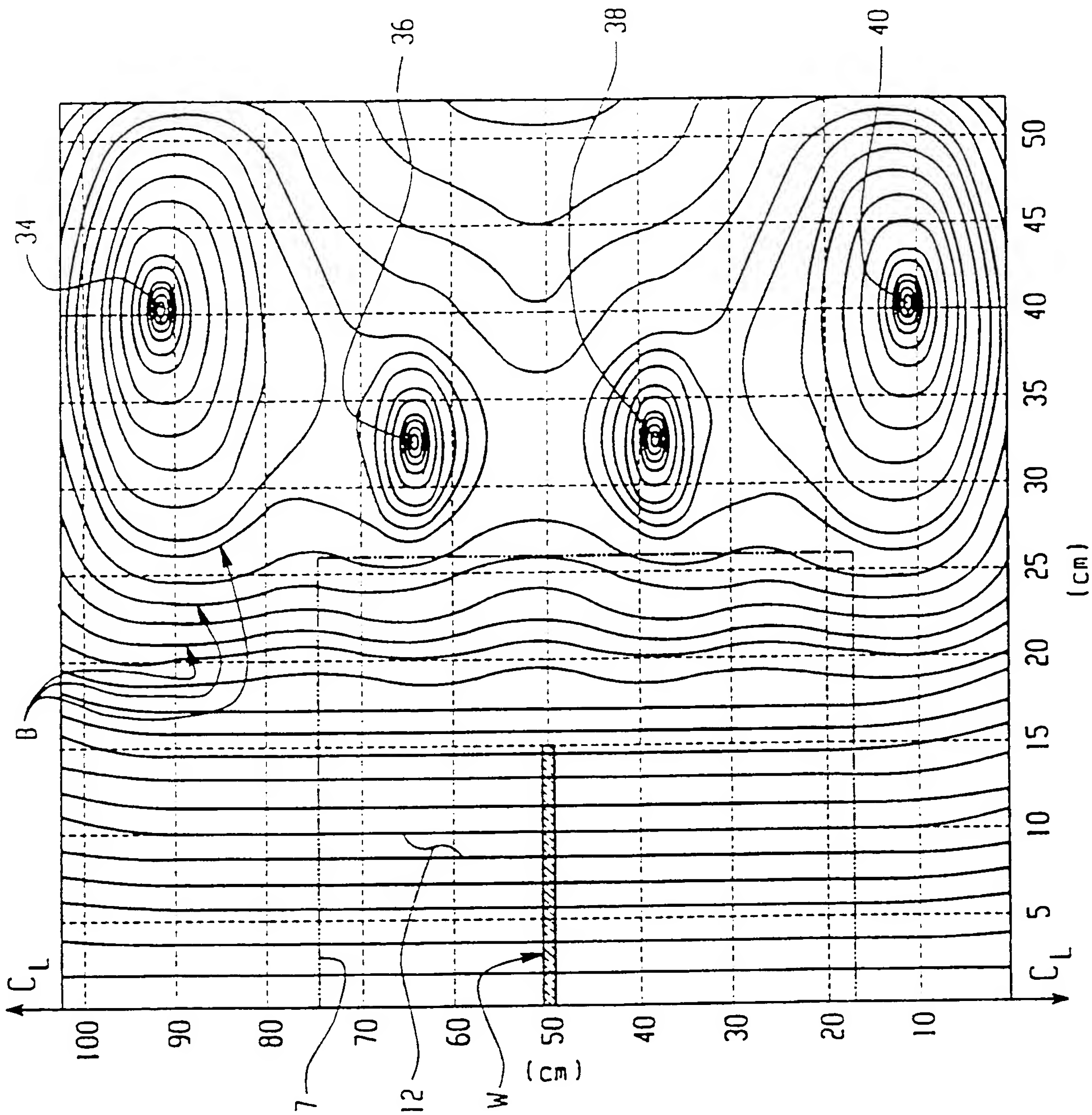
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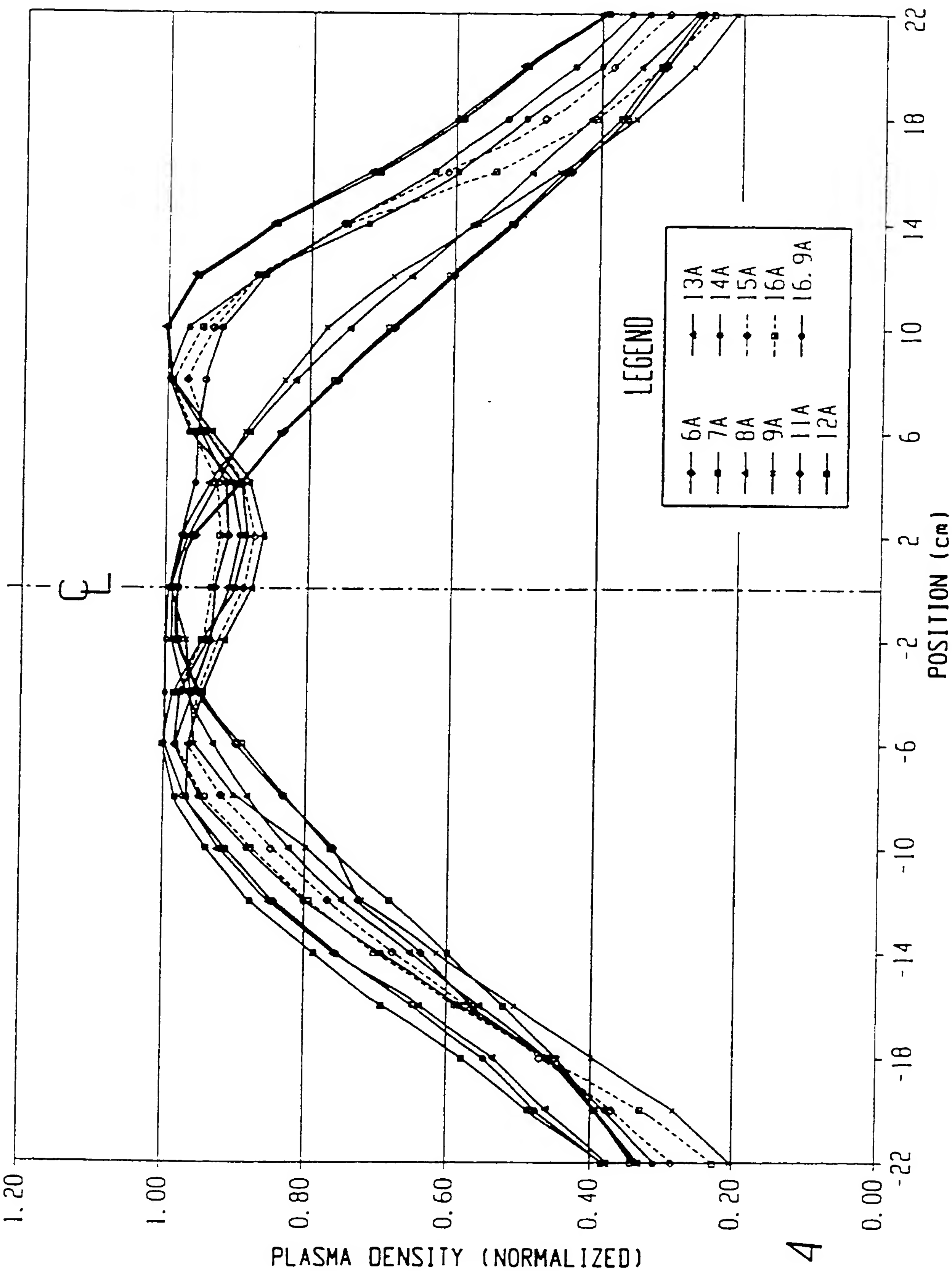
Fig. 3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-10
-6
-2
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10
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18
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12A
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14A
15A
16A
16.9A

Fig. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/03003

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01J37/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	WO 00 32839 A (LIU WEI ;BRYAN MICHAEL A (US); ROTH IAN S (US); SILICON GENESIS CO) 8 June 2000 (2000-06-08) page 2, line 7 - line 18 page 9, line 16 - line 19 page 10, line 18 -page 11, line 2 figure 2 ---	1-4, 6-11,13, 14
Y	US 5 653 811 A (CHAN CHUNG) 5 August 1997 (1997-08-05)	1-4, 6-11,13, 14
A	column 1, line 48 - line 55 column 2, line 65 -column 3, line 18 column 3, line 53 - line 67 figure 1 ---	15
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[X] Further documents are listed in the continuation of box C

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
8 January 2001	22/01/2001

Name and mailing address of the ISA	Authorized officer
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2

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 654 043 A (SHAO JIQUN ET AL) 5 August 1997 (1997-08-05) column 5, line 36 - line 39 figure 2 -----	1-4, 6-11,13, 14

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/03003

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